Lesson 4

Vertical Motion and Atmospheric Stability

This lesson describes the vertical structure of the atmosphere, atmospheric stability and the corresponding vertical motion. Adiabatic diagrams are introduced to help explain atmospheric conditions affecting pollutant dispersion.

Goal

To familiarize you with the vertical temperature structure of the atmosphere and to introduce its relationship to plume dispersion.

Objectives

Upon completing this lesson, you will be able to do the following:

1. Explain the concept of buoyancy
2. Define *lapse rate* and distinguish between dry adiabatic, wet adiabatic, and environmental lapse rates
3. Describe stable, unstable and neutral conditions
4. Given an adiabatic diagram, identify the atmospheric stability category represented
5. Describe how atmospheric stability and inversions affect air pollutant dispersion
6. Describe how four different types of inversions form
7. List five types of plume behavior and relate each to atmospheric conditions

Introduction

The previous lesson discusses horizontal motion of the atmosphere. Vertical motion is equally important in air pollution meteorology, for the degree of vertical motion helps to determine how much air is available for pollutant dispersal. Vertical motions can be attributed to high and low pressure systems, air lifting over terrain or fronts and convection. There are a number of basic principles related to vertical motion that you must be familiar with before you can understand the mechanics and conditions of vertical motion. These principles are presented first and are followed by discussions of instability, stability, and plume behavior. Inversion, where the temperature of the air increases with height, is also discussed.

Principles Related to Vertical Motion

Parcel

Throughout this lesson we will be discussing a *parcel* of air. This theoretically infinitesimal parcel is a relatively well-defined body of air (a constant number of molecules) that acts as a whole. Self-contained, it does not readily mix with the surrounding air. The exchange of heat between the parcel and its surroundings is minimal, and the temperature within the parcel is generally uniform. The air inside a balloon is an analogy for an air parcel.

Buoyancy Factors

Atmospheric temperature and pressure influence the buoyancy of air parcels. Holding other conditions constant, the temperature of air (a fluid) increases as atmospheric pressure increases, and conversely decreases as pressure decreases. With respect to the atmosphere, where air pressure decreases with rising altitude, the normal temperature profile of the troposphere is one where temperature decreases with height.

An air parcel that becomes warmer than the surrounding air (for example, by heat radiating from the earth's surface), begins to expand and cool. As long as the parcel's temperature is greater that the surrounding air, the parcel is less dense than the cooler surrounding air. Therefore, it rises, or is buoyant. As the parcel rises, it expands thereby decreasing its pressure and, therefore, its temperature decreases as well. The initial cooling of an air parcel has the opposite effect. In short, warm air rises and cools, while cool air descends and warms.

The extent to which an air parcel rises or falls depends on the relationship of its temperature to that of the surrounding air. As long as the parcel's temperature is greater, it will rise; as long as the parcel’s temperature is cooler, it will descend. When the temperatures of the parcel and the surrounding air are the same, the parcel will neither rise nor descend unless influenced by wind flow.

Lapse Rates

The **lapse rate** is defined as the rate at which air temperature changes with height. The actual lapse rate in the atmosphere is approximately −6 to −7°C per km (in the troposphere) but it varies widely depending on location and time of day. We define a temperature *decrease* with height as a negative lapse rate and a temperature *increase* with height as a positive lapse rate.

How the atmosphere behaves when air is displaced vertically is a function of atmospheric stability. A stable atmosphere resists vertical motion; air that is displaced vertically in a stable atmosphere tends to return to its original position. This atmospheric characteristic determines the ability of the atmosphere to disperse pollutants emitted into it. To understand atmospheric stability and the role it plays in pollution dispersion, it is important to understand the mechanics of the atmosphere as they relate to vertical atmospheric motion.

Dry Adiabatic

For the most part, a parcel of air does not exchange heat across its boundaries. Therefore, an air parcel that is warmer than the surrounding air does not transfer heat to the atmosphere. Any temperature changes that occur within the parcel are caused by increases or decreases of molecular activity within the parcel. Such changes, occur adiabatically, and are due only to the change in atmospheric pressure as a parcel moves vertically. An adiabatic process is one in which there is no transfer of heat or mass across the boundaries of the air parcel. In an adiabatic process, compression results in heating and expansion results in cooling. A dry air parcel rising in the atmosphere cools at the dry adiabatic rate of 9.8°C/1000m and has a lapse rate of –9.8°C/1000m. Likewise, a dry air parcel sinking in the atmosphere heats up at the dry adiabatic rate of 9.8°C/1000m and has a lapse rate of 9.8°C/1000m. Air is considered dry, in this context, as long as any water in it remains in a gaseous state.

The dry adiabatic lapse rate is a fixed rate, entirely independent of ambient air temperature. A parcel of dry air moving upward in the atmosphere, then, will always cool at the rate of 9.8°C/1000 m, regardless of its initial temperature or the temperature of the surrounding air. You will see later that the dry adiabatic lapse rate is central to the definition of atmospheric stability.

A simple adiabatic diagram demonstrates the relationship between elevation and temperature. The dry adiabatic lapse rate is indicated by a broken line, as shown in Figure 4-1, beginning at various temperatures along the horizontal axis. Remember that the slope of the line remains constant, regardless of its initial temperature on the diagram.

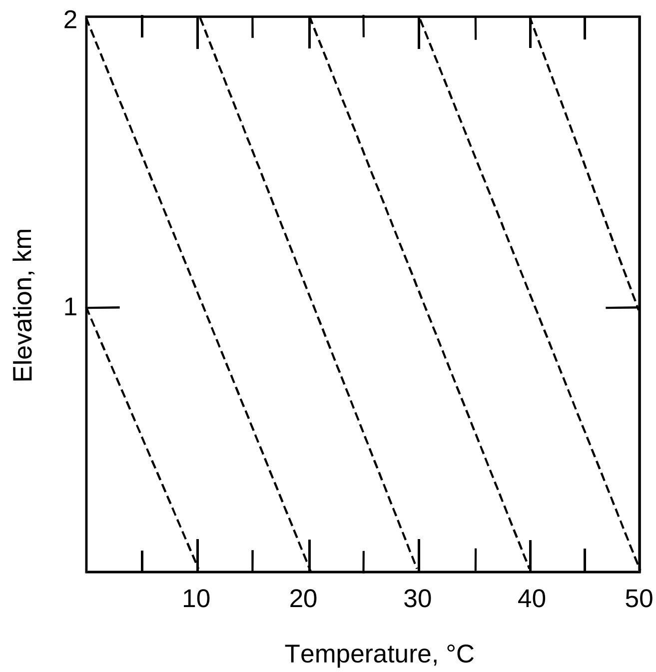


Figure 4-1. Dry adiabatic lapse rate

Wet Adiabatic

A rising parcel of dry air containing water vapor will continue to cool at the dry adiabatic lapse rate until it reaches its condensation temperature, or dew point. At this point the pressure of the water vapor equals the saturation vapor pressure of the air, and some of the water vapor begins to condense. Condensation releases latent heat in the parcel, and thus the cooling rate of the parcel slows. This new rate, called the **wet adiabatic lapse rate**, is shown in Figure 4-2. Unlike the dry adiabatic lapse rate, the wet adiabatic lapse rate is not constant but depends on temperature and pressure. In the middle troposphere, however, it is assumed to be approximately –6 to –7^{o}C/1000 m.

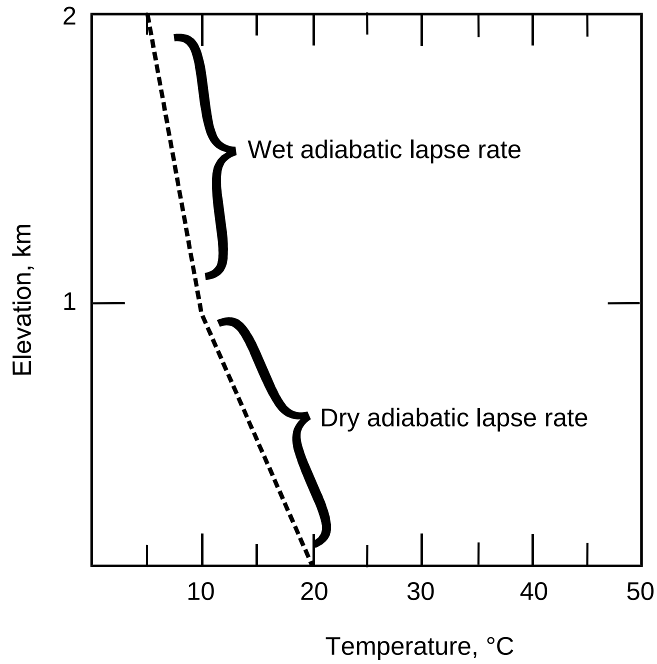


Figure 4-2. Wet adiabatic lapse rate

Environmental

As mentioned previously, the actual temperature profile of the ambient air shows the **environmental lapse rate**. Sometimes called the **prevailing** or **atmospheric lapse rate**, it is the result of complex interactions of meteorological factors, and is usually considered to be a decrease in temperature with height. It is particularly important to vertical motion since surrounding air temperature determines the extent to which a parcel of air rises or falls. As Figure 4-3 shows, the temperature profile can vary considerably with altitude, sometimes changing at a rate greater than the dry adiabatic lapse rate and some times changing less. The condition when temperature actually increases with altitude is referred to as a **temperature inversion**. In Figure 4-4, the temperature inversion occurs at elevations of from 200 to 350 m. This situation is particularly important in air pollution, because it limits vertical air motion.

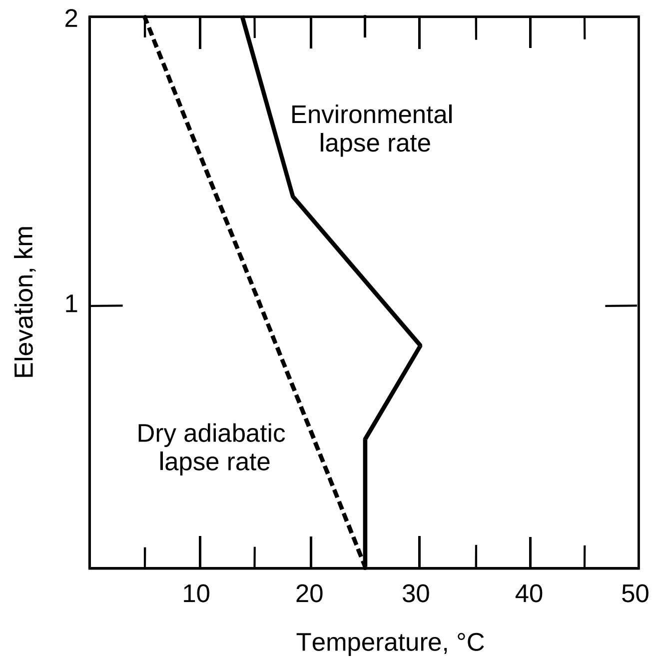


Figure 4-3. Environmental lapse rate

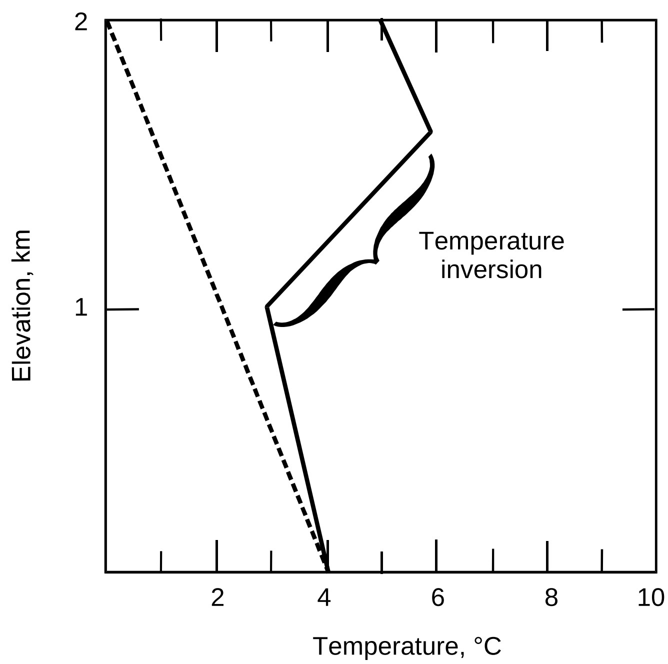


Figure 4-4. Temperature inversion

Mixing Height

Remember the analogy of the air parcel as a balloon. Figure 4-5 shows three ways in which the adiabatic lapse rate affects buoyancy. In each situation assume that the balloon is filled at ground level with air at 20^{o}C, then lifted manually to a height of 1 km (for example, lifted by the wind over a mountain ridge). The air in the balloon will expand and cool to about 10^{o}C. Whether the balloon rises or falls upon release depends on the surrounding air temperature and density. In situation "A," the balloon will rise because it remains warmer and less dense than the surrounding air. In situation "B," it will sink because it is cooler and more dense. In situation "C," however, it will not move at all, because the surrounding air is the same temperature and density.

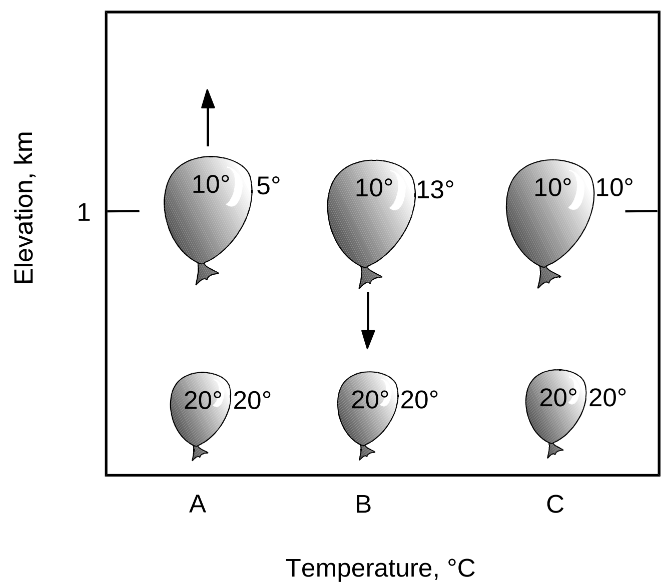


Figure 4-5. Relationship of adiabatic lapse rate to air temperature

The same principles apply in real atmospheric conditions when an air parcel is heated near the surface and rises, and a cool parcel descends to take its place. The relationship of the adiabatic lapse rate and the environmental lapse rate should now be apparent. The latter controls the extent to which a parcel of air can rise or descend.

In an adiabatic diagram, as shown in Figure 4-6, the point at which the air parcel cooling at the dry adiabatic lapse rate intersects the ambient temperature profile “line” is known as the **mixing height**. This is the air parcel's maximum level of ascendance. In cases where no intersection occurs (when the environmental lapse rate is consistently greater than the adiabatic lapse rate), the mixing height may extend to great heights in the atmosphere. The air below the mixing height is the **mixing layer**. The deeper the mixing layer, the greater the volume of air into which pollutants can be dispersed.

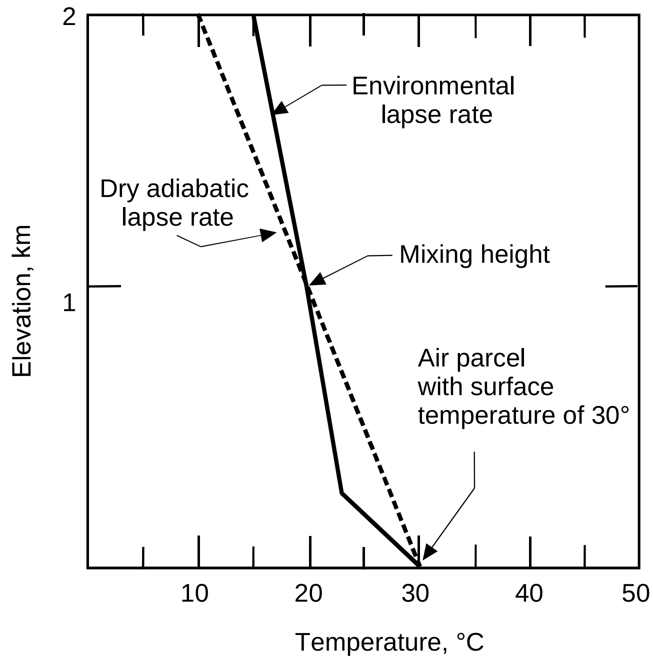


Figure 4-6. Mixing height

Atmospheric Stability

The degree of stability of the atmosphere is determined by the temperature difference between an air parcel and the air surrounding it. This difference can cause the parcel to move vertically (i.e., it may rise or fall). This movement is characterized by four basic conditions that describe the general stability of the atmosphere. In **stable** conditions, this vertical movement is discouraged, whereas in **unstable** conditions the air parcel tends to move upward or downward and to continue that movement. When conditions neither encourage nor discourage air movement beyond the rate of adiabatic heating or cooling, they are considered **neutral**. When conditions are extremely stable, cooler air near the surface is trapped by a layer of warmer air above it. This condition, called an **inversion**, allows virtually no vertical air motion. These conditions are directly related to pollutant concentrations in the ambient air.

Unstable Conditions

Remember that an air parcel that begins to rise will cool at the dry adiabatic lapse rate until it reaches the dew point at which point it will cool at the wet adiabatic lapse rate. This assumes that the surrounding atmosphere has a lapse rate greater than the adiabatic lapse rate (cooling at more than 9.8°C/1000 m), so that the rising parcel will continue to be warmer than the surrounding air. This is a **superadiabatic lapse** rate. As Figure 4-7 shows, the temperature difference between the actual environmental lapse rate and the dry adiabatic lapse rate actually increases with height, and buoyancy is enhanced.

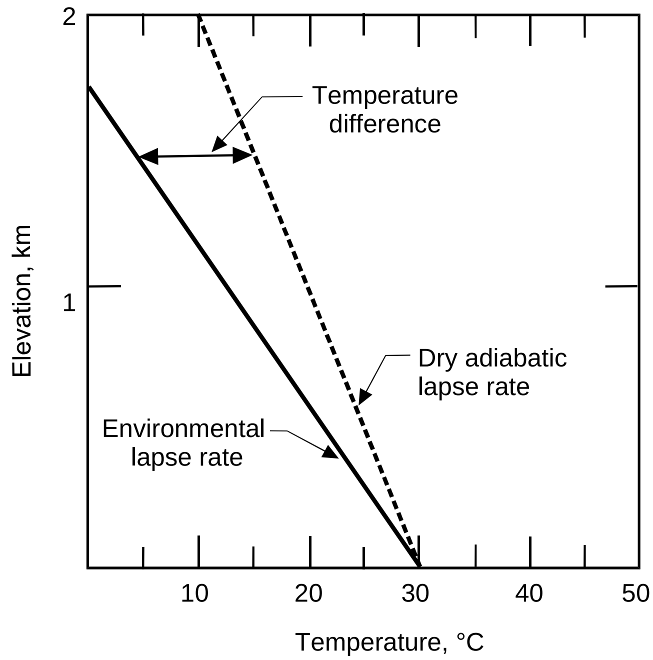


Figure 4-7. Enhanced buoyancy associated with instability (superadiabatic lapse rate)

As the air rises, cooler air moves underneath. It, in turn, may be heated by the earth's surface and begin to rise. Under such conditions, vertical motion in both directions is enhanced, and considerable vertical mixing occurs. The degree of instability depends on the degree of difference between the environmental and dry adiabatic lapse rates. Figure 4-8 shows both slightly unstable and very unstable conditions.

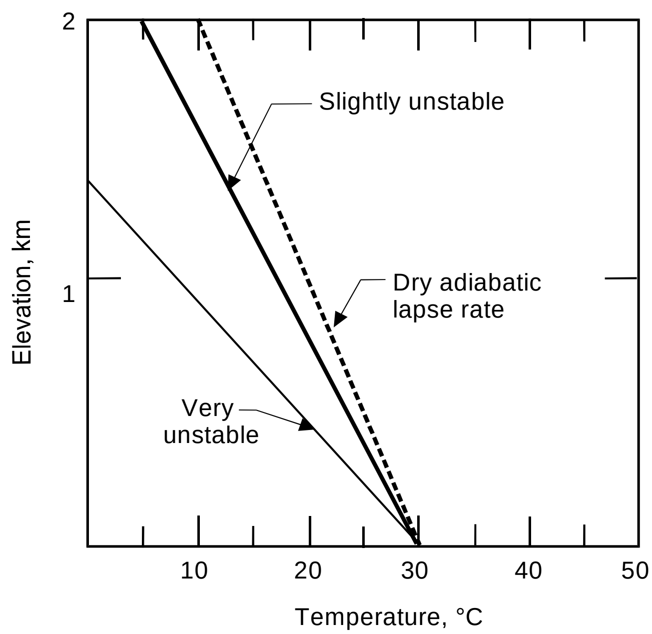


Figure 4-8. Unstable conditions

Unstable conditions most commonly develop on sunny days with low wind speeds where strong insolation is present. The earth rapidly absorbs heat and transfers some of it to the surface air layer. There may be one buoyant air mass if the thermal properties of the surface are uniform, or there may be numerous parcels if the thermal properties vary. The air warms, becomes less dense than the surrounding air and rises.

Another condition that may lead to instability is the cyclone (low pressure system), which is characterized by rising air, clouds, and precipitation.

Neutral Conditions

When the environmental lapse rate is the same as the dry adiabatic lapse rate, the atmosphere is in a state of neutral stability (Figure 4-9). Vertical air movement is neither encouraged nor hindered. The neutral condition is important as the dividing line between stable and unstable conditions. Neutral stability occurs on windy days or when there is cloud cover such that strong heating or cooling of the earth's surface is not occurring.

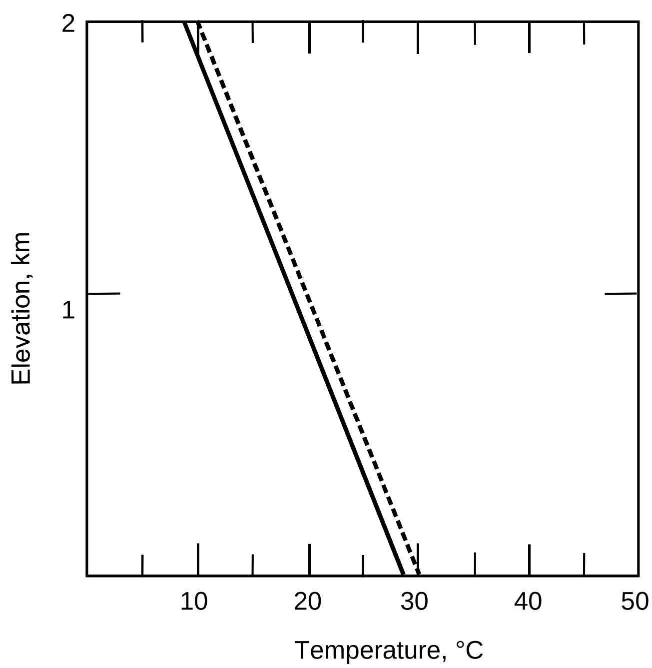


Figure 4-9. Neutral conditions

Stable Conditions

When the environmental lapse rate is less than the adiabatic lapse rate (cools at less than 9.8°C/1000 m), the air is stable and resists vertical motion. This is a **subadiabatic lapse** rate. Air that is lifted vertically will remain cooler, and therefore more dense than the surrounding air. Once the lifting force is removed, the air that has been lifted will return to its original position (Figure 4-10). Stable conditions occur at night when there is little or no wind.

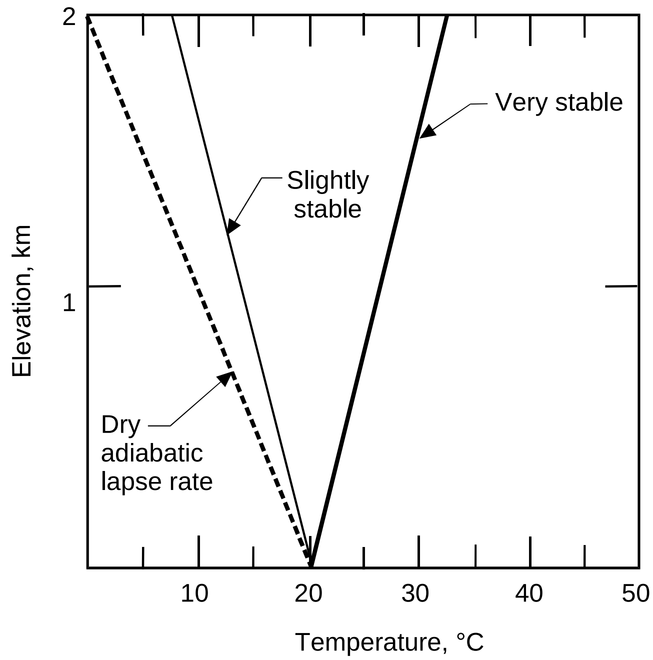


Figure 4-10. Stable conditions

Conditional Stability and Instability

In the previous discussion of stability and instability, we have assumed that a rising air parcel cools at the dry adiabatic lapse rate. Very often, however, the air parcel becomes saturated (reaches its dew point) and begins to cool more slowly, at the wet adiabatic lapse rate. This change in the rate of cooling may change the conditions of stability. Conditional instability occurs when the environmental lapse rate is greater than the wet adiabatic lapse rate but less than the dry rate. This is illustrated in Figure 4-11. Stable conditions occur up to the condensation level and unstable conditions occur above it.

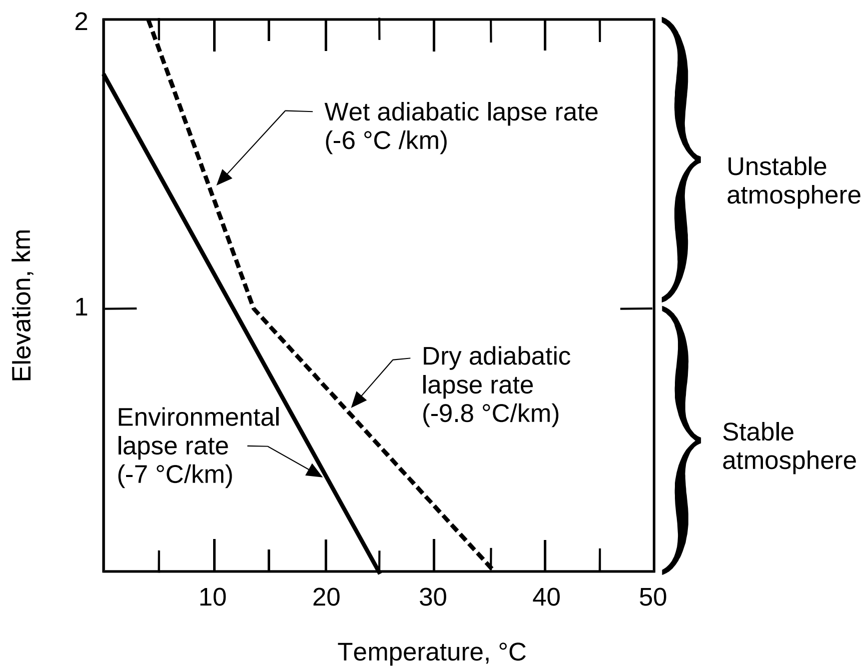


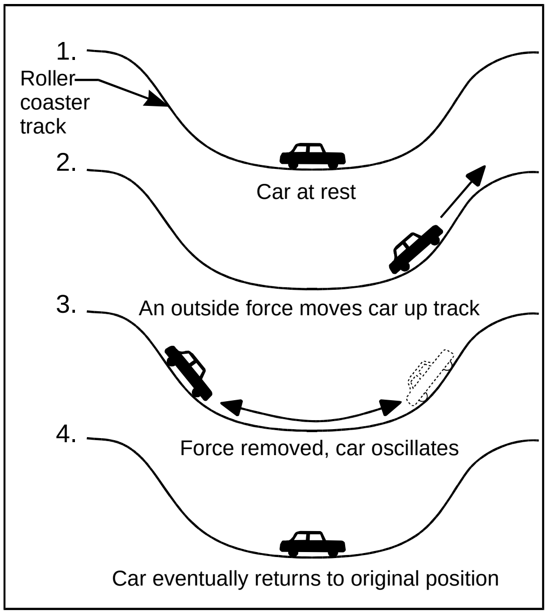
Figure 4-11. Conditional stability

Illustration of Atmospheric Stability Conditions

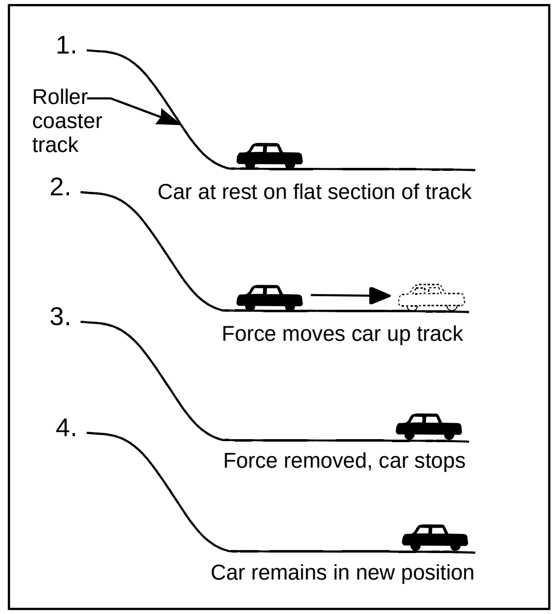
Figure 4-12 illustrates the various stability categories. These analogies are intended to illustrate the different atmospheric stability conditions. Figure 4-12 (a) depicts stable atmospheric conditions. Notice that when the lifting force is removed, the car eventually returns to its original position. Since the car resists displacement from its original position, it is in a stable environment.

Figure 4-12 (b) depicts neutral conditions. When a force is applied to the car it moves as long as the force is maintained. When the force is removed, the car stops and remains in its new position. This condition represents neutral stability.

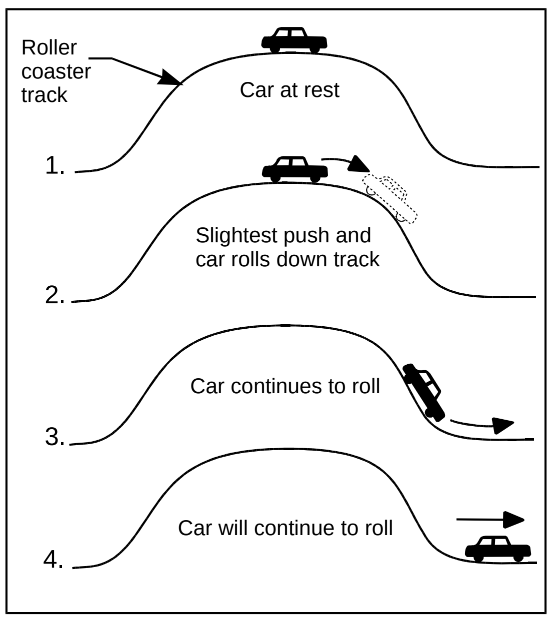
Figure 4-12 (c) depicts unstable conditions. Once a force is applied to the car it will continue to move even after the force is removed.



(a) Stable conditions



(b) Neutral conditions



(c) Unstable conditions

Figure 4-12. Atmospheric stability conditions

Inversions

An inversion occurs when air temperature increases with altitude. This situation occurs frequently but is generally confined to a relatively shallow layer. Plumes emitted into air layers that are experiencing an inversion (inverted layer) do not disperse very much as they are transported with the wind. Plumes that are emitted above or below an inverted layer do not penetrate that layer, rather these plumes are trapped either above or below that inverted layer. An example of the lapse rate for an inversion is depicted in Figure 4-13. High concentrations of air pollutants are often associated with inversions since they inhibit plume dispersion. The four major types of inversions are caused by different atmospheric interactions and can persist for different amounts of time.

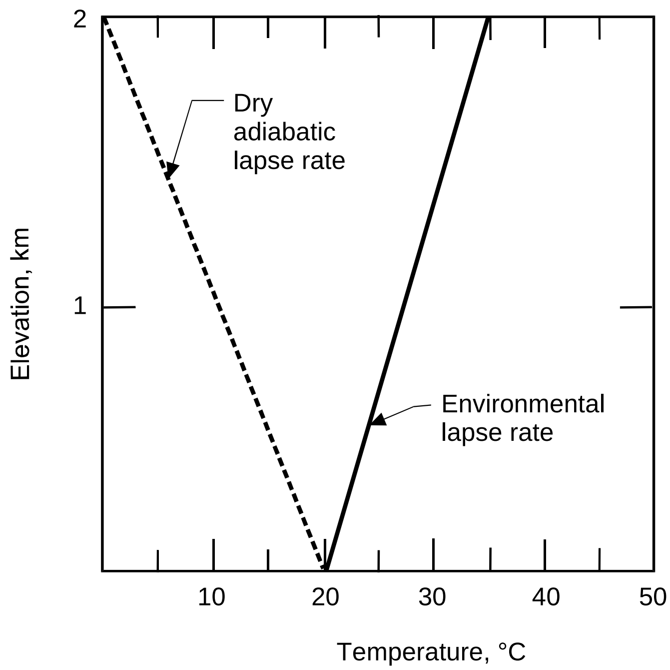


Figure 4-13. Temperature inversion

Radiation

The **radiation inversion** is the most common form of surface inversion and occurs when the earth's surface cools rapidly. As the earth cools, so does the layer of air close to the surface. If this air cools to a temperature below that of the air above, it becomes very stable, and the layer of warmer air impedes any vertical motion.

Radiation inversions usually occur in the late evening through the early morning under clear skies with calm winds, when the cooling effect is greatest. The same conditions that are conducive to nocturnal radiation inversions are also conducive to instability during the day. Diurnal cycles of daytime instability and nighttime inversions are relatively common. Therefore, the effects of radiation inversions are often short-lived. Pollutants trapped by the inversions are dispersed by vigorous vertical mixing after the inversion breaks down shortly after sunrise. Figure 4-14 illustrates this diurnal cycle.

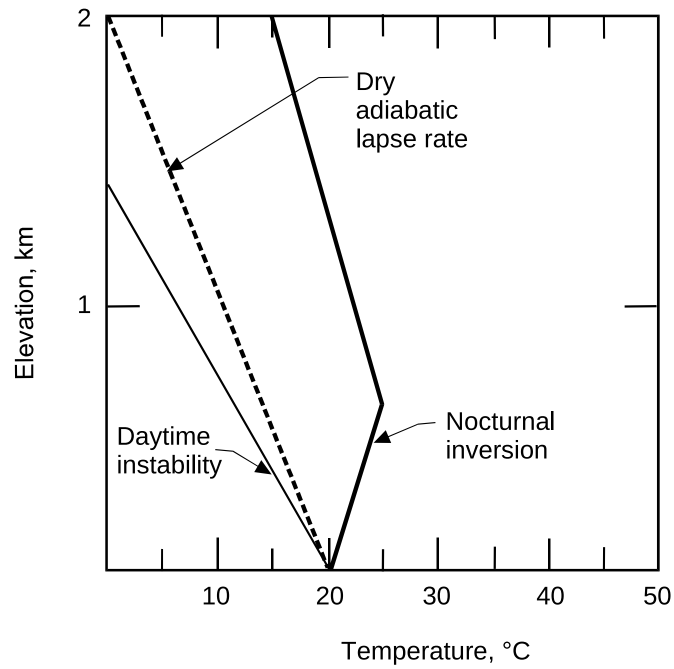


Figure 4-14. Diurnal cycle

In some cases, however, the daily warming that follows a nocturnal radiation inversion may not be strong enough to erode the inversion layer. For example, thick fog may accompany the inversion and reduce the effect of sunlight the next day. Under the right conditions, several days of radiation inversion, with increasing pollutant concentrations, may result. This situation is most likely to occur in an enclosed valley, where nocturnal, cool, downslope air movement can reinforce a radiation inversion and encourage fog formation.

In locations where radiation inversions are common and tend to be relatively close to the surface, tall stacks that emit pollutants above the inversion layer can help reduce surface-level pollutant concentrations.

Subsidence

The **subsidence inversion** (Figure 4-15) is almost always associated with anticyclones (high pressure systems). Recall that air in an anticyclone descends and flows outward in a clockwise rotation. As the air descends, the higher pressure at lower altitudes compresses and warms it at the dry adiabatic lapse rate. Often this warming occurs at a rate faster than the environmental lapse rate. The inversion layer thus formed is often elevated several hundred meters above the surface during the day. At night, because of the surface air cooling, the base of a subsidence inversion often descends, perhaps to the ground. In fact, the clear, cloudless days characteristic of anticyclones encourage radiation inversions, so that there may be a surface inversion at night and an elevated inversion during the day. Although the mixing layer below the inversion may vary diurnally, it will never become very deep.

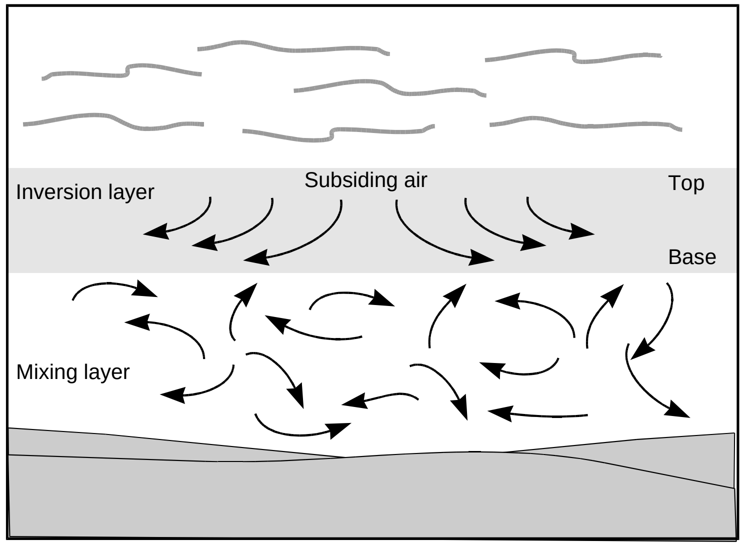


Figure 4-15. Subsidence inversion

Subsidence inversions, unlike radiation inversions, last a relatively long time. This is because they are associated with both the semipermanent anticyclones centered on each ocean and the slow-moving migratory anticyclones moving generally west to east in the United States.

When an anticyclone stagnates, pollutants emitted into a mixing layer cannot be diluted. As a result, over a period of days, pollutant concentrations may rise. The most severe air pollution episodes in the United States have occurred either under a stagnant migratory anticyclone (for example, New York in November, 1966 and Pennsylvania in October, 1948) or under the eastern edge of the Pacific semipermanent anticyclone (Los Angeles).

Frontal

Lesson 3 mentions frontal trapping, the inversion that is usually associated with both cold and warm fronts. At the leading edge of either front, the warm air overrides the cold, so that little vertical motion occurs in the cold air layer closest to the surface (Figure 4-16). The strength of the inversion depends on the temperature difference between the two air masses. Because fronts are moving horizontally, the effects of the inversion are usually short-lived, and the lack of vertical motion is often compensated by the winds associated with the frontal passage.

However, when fronts become stationary, inversion conditions may be prolonged.

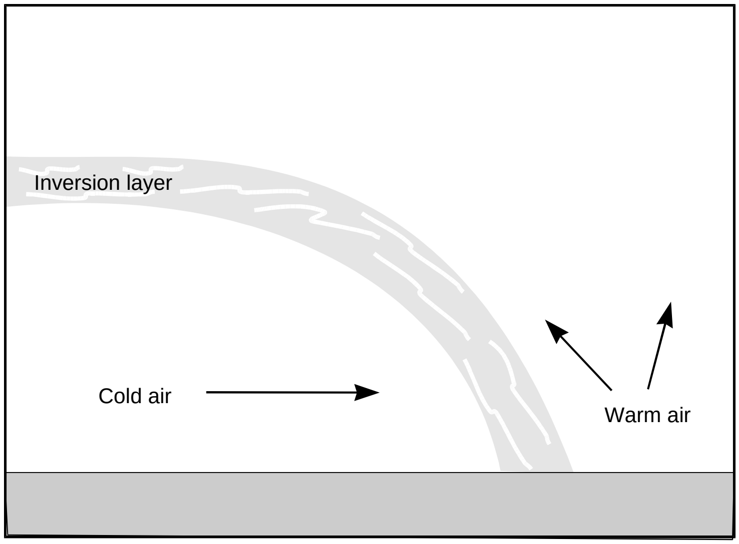


Figure 4-16. Frontal inversion (cold front)

Advection

Advection inversions are associated with the horizontal flow of warm air. When warm air moves over a cold surface, conduction and convection cools the air closest to the surface, causing a surface-based inversion (Figure 4-17). This inversion is most likely to occur in winter when warm air passes over snow cover or extremely cold land.

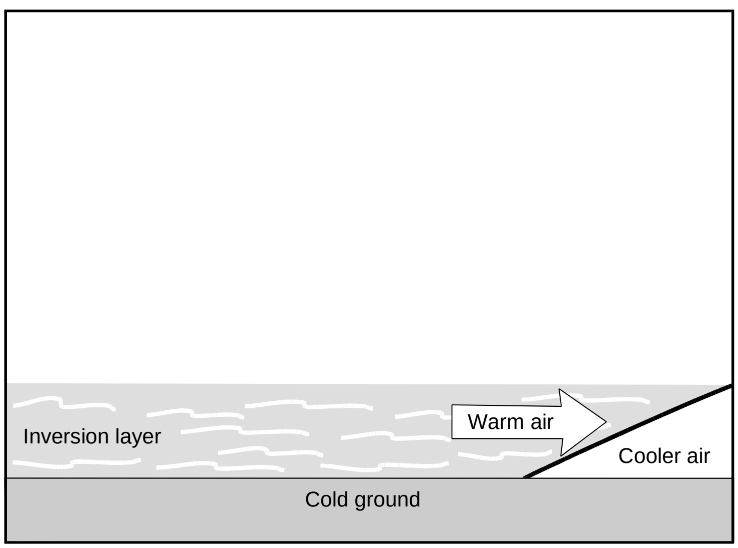


Figure 4-17. Surface-based advection inversion

Another type of advection inversion develops when warm air is forced over the top of a cooler air layer. This kind of inversion is common on the eastern slopes of mountain ranges (Figure 4-18), where warm air from the west overrides cooler air on the eastern side of the mountains. Denver often experiences such inversions. Both kinds of advection inversions are vertically stable but may have strong winds under the inversion layer.

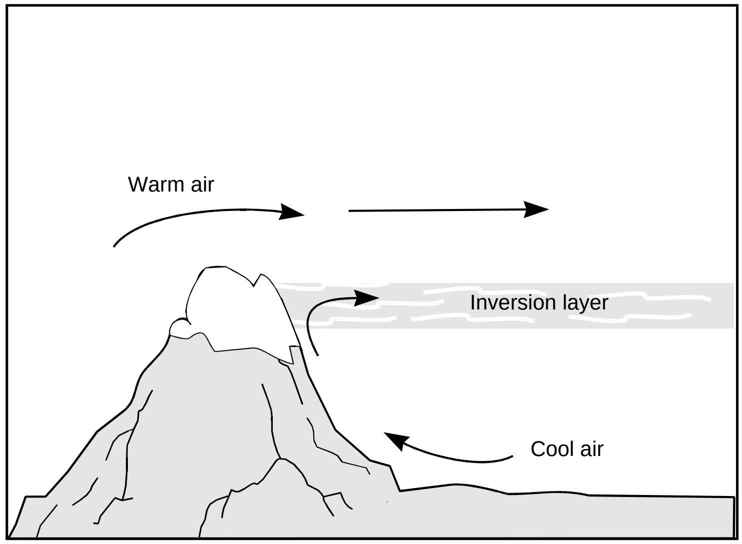


Figure 4-18. Terrain-based advection inversion

Stability and Plume Behavior

The degree of atmospheric stability and the resulting mixing height have a large effect on pollutant concentrations in the ambient air. Although the discussion of vertical mixing did not include a discussion of horizontal air movement, or wind, you should be aware that horizontal motion does occur under inversion conditions. Pollutants that cannot be dispersed upward may be dispersed horizontally by surface winds.

The combination of vertical air movement and horizontal air flow influences the behavior of plumes from point sources (stacks). Lesson 6 will discuss plume dispersion in greater detail. However, this lesson will describe several kinds of plumes that are characteristic of different stability conditions.

The **looping plume** of Figure 4-19 occurs in highly unstable conditions and results from turbulence caused by the rapid overturning of air. While unstable conditions are generally favorable for pollutant dispersion, momentarily high ground-level concentrations can occur if the plume loops downward to the surface.

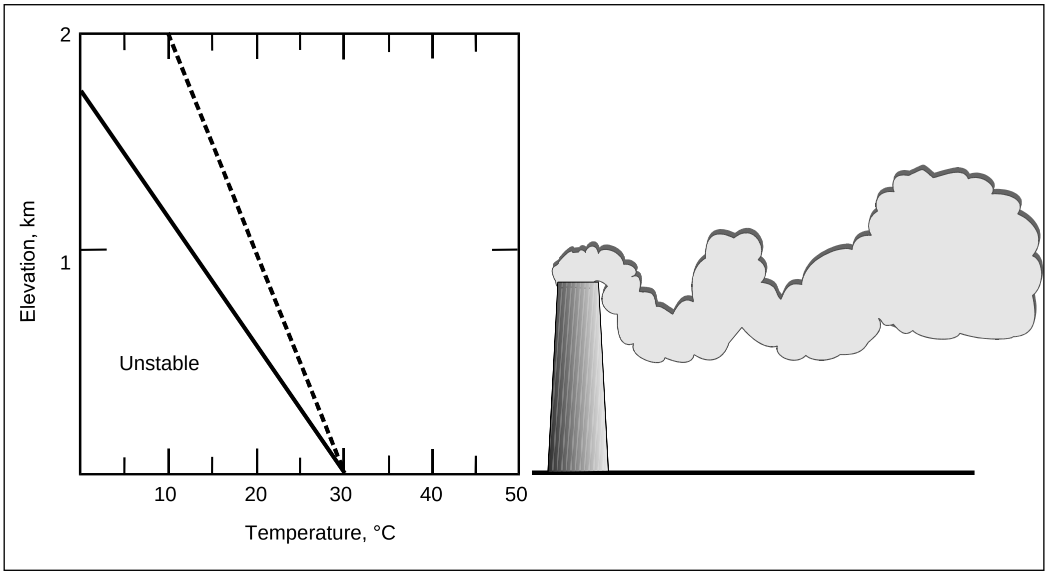


Figure 4-19. Looping plume

The **fanning plume** (Figure 4-20) occurs in stable conditions. The inversion lapse rate discourages vertical motion without prohibiting horizontal motion, and the plume may extend downwind from the source for a long distance. Fanning plumes often occur in the early morning during a radiation inversion.

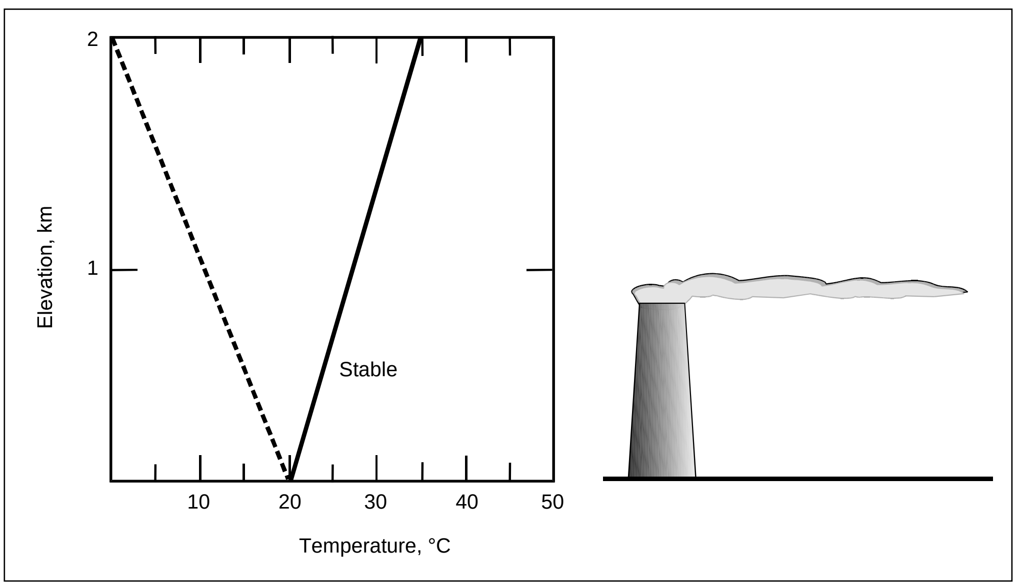


Figure 4-20. Fanning plume

The **coning plume** (Figure 4-21) is characteristic of neutral conditions or slightly stable conditions. It is likely to occur on cloudy days or on sunny days between the breakup of a radiation inversion and the development of unstable daytime conditions.

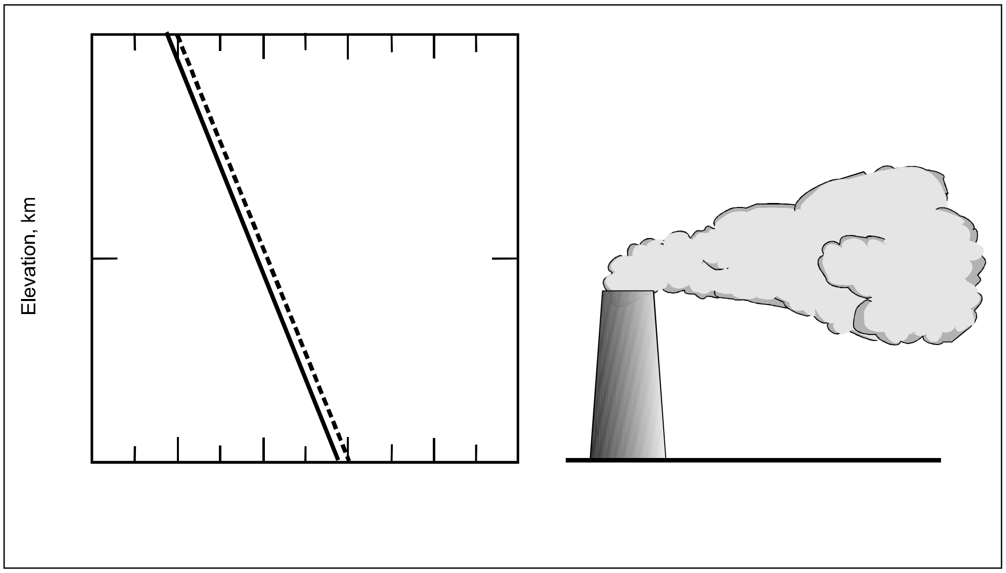


Figure 4-21. Coning plume

Obviously a major problem for pollutant dispersion is an inversion layer, which acts as a barrier to vertical mixing. The height of a stack in relation to the height of the inversion layer may often influence ground-level pollutant concentrations during an inversion.

When conditions are unstable above an inversion (Figure 4-22), the release of a plume above the inversion results in effective dispersion without noticeable effects on ground-level concentrations around the source. This condition is known as **lofting**.

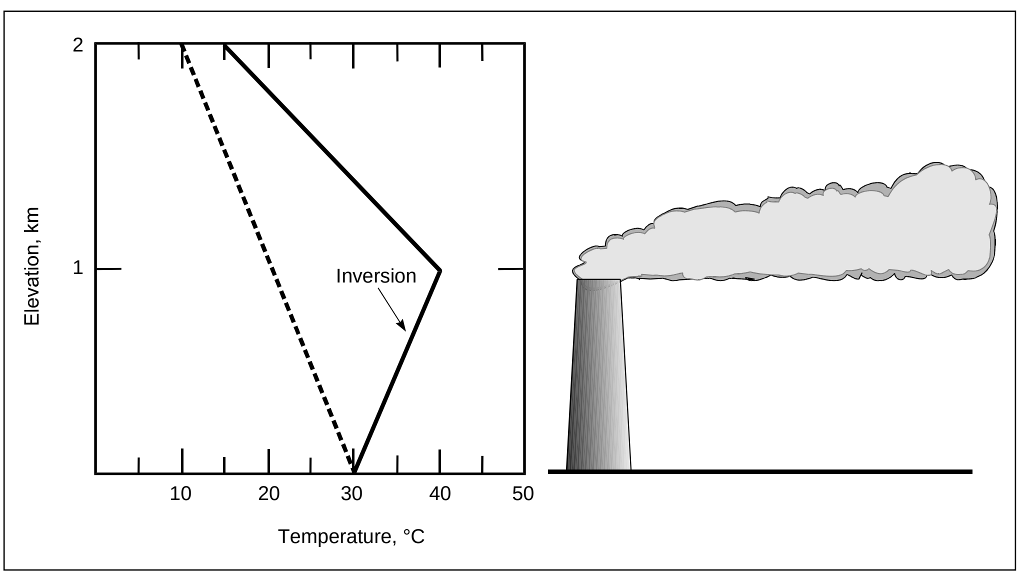


Figure 4-22. Lofting plume

If the plume is released just under an inversion layer, a serious air pollution situation could develop. As the ground warms in the morning, air below an inversion layer becomes unstable. When the instability reaches the level of the plume that is still trapped below the inversion layer, the pollutants can be rapidly transported down toward the ground (Figure 4-23). This is known as **fumigation**. Ground-level pollutant concentrations can be very high when fumigation occurs. Sufficiently tall stacks can prevent fumigation in most cases.

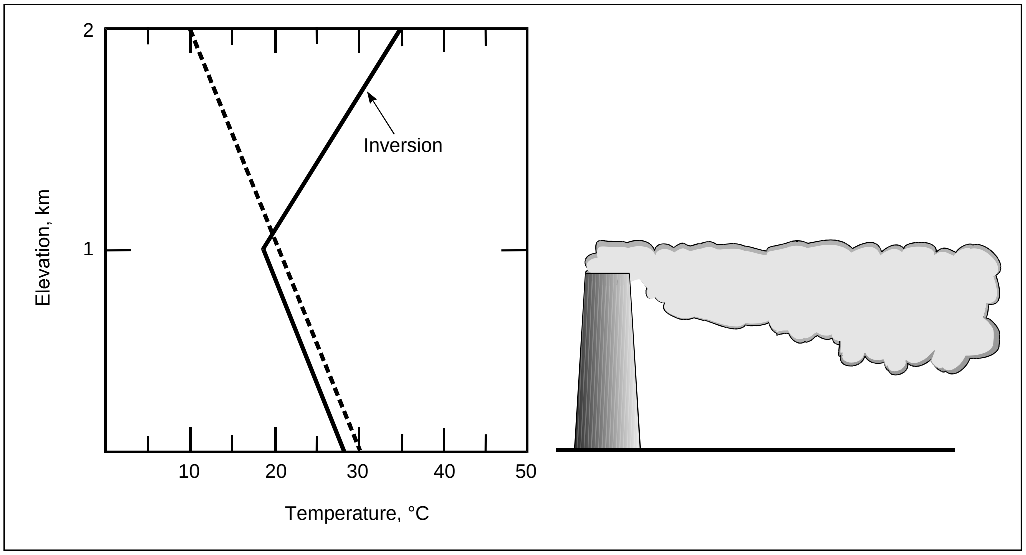


Figure 4-23. Fumigation

Thus far you have learned the basic meteorological conditions and events that influence the movement and dispersal of air pollutants in the atmosphere. Lesson 6 explores more fully the behavior of pollutants around point sources, while the next lesson discusses the instrumentation used for meteorological measurement.

Review Exercise

1. An infinitesimally small, well-defined body of air that does not readily mix with the surrounding air is a(n):
   a. Air column
   b. Air mass
   c. Air parcel
   d. Hot air balloon
   e. b and c

2. The temperature of air ____________________ as atmospheric pressure increases.
   a. Increases
   b. Decreases

3. What two atmospheric factors influence the buoyancy of an air parcel?

   ____

   ____

4. If the temperature of an air parcel is cooler than the surrounding air, it will usually:
   a. Ascend
   b. Descend
   c. Stay in the same place

5. The environmental, or prevailing, lapse rate can be determined from the:
   a. Rate of pressure change in the atmosphere
   b. Rate of wet air vs. pressure change
   c. Temperature profile of the atmosphere
   d. Rate of frontal system passage

6. Changes in the temperature of an air parcel that are due to changes in atmospheric pressure are called:
   a. Advective
   b. Adiabatic
   c. Slope
   d. Prevailing

7. The dry adiabatic lapse rate is:
   a. –6°C/1000 m
   b. < 1°C/1000 m
   c. –9.8°C/1000 m
   d. –7.5°C/1000 m

8. True or False? The dry adiabatic lapse rate is fixed and entirely independent of ambient air temperature.
    a. True
    b. False

9. A displaced air parcel cools at the wet adiabatic lapse rate once it becomes ____________________.

10. At the wet adiabatic lapse rate, the cooling rate of the air parcel is usually:
    a. The same as at the dry rate
    b. Slower than at the dry rate
    c. Faster than at the dry rate

11. The actual temperature profile of the ambient air can be used to determine the ____________________ lapse rate.

12. True or False? The environmental lapse rate influences the extent to which a parcel of air can rise or descend.
    a. True
    b. False

13. The maximum level to which a parcel of air will ascend under a given set of conditions is known as the:
    a. Ascend/descend level
    b. Mixing trough
    c. Mixing height
    d. Mixing layer

14. The adiabatic lapse rate for a given air parcel will intersect the environmental lapse rate at the:
    a. Mixing trough
    b. Moisture rate
    c. Mixing height
    d. None of the above

15. A large mixing layer implies that air pollutants have a ____________________ volume of air for dilution.
    a. Greater
    b. Lesser

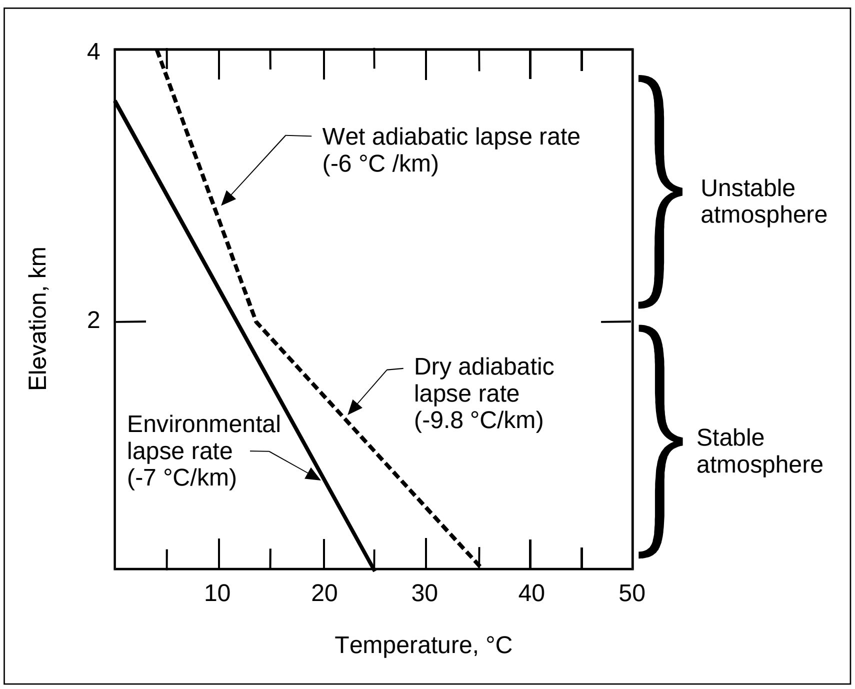
16. True or False? A stable atmosphere resists vertical motion.
    a. True
    b. False

17. Vertical mixing due to buoyancy is increased when atmospheric conditions are:
    a. Unstable
    b. Neutral
    c. Stable
    d. Extremely stable

18. Unstable atmospheric conditions most commonly develop:
    a. On cloudy days
    b. On sunny days
    c. On cloudy nights
    d. On clear nights

19. On cloudy days with no strong surface heating, atmospheric conditions are likely to be:
    a. Unstable
    b. Neutral
    c. Stable
    d. Extremely stable

20. In this diagram, a displaced air parcel becomes saturated at an elevation of 2 km. Which of the following stability conditions does the diagram depict?



    a. Stable below 1 km
    b. Conditional stability above 1 km
    c. Neutral from 0 to 2 km
    d. Conditional instability above 2 km

21. A(n) ____________________ acts as a lid on vertical air movement.

22. When the earth's surface cools rapidly, such as between late night and early morning under clear skies, a(n) ____________________ inversion is likely to occur.

23. When vigorous vertical mixing follows a radiation inversion, pollutant plumes will:

    a. Be trapped near the surface
    b. Be dispersed away from their source

24. True or False? A high pressure system can cause an elevated temperature inversion to form.

    a. True
    b. False

25. The subsidence inversion is associated with ____________________ because it usually forms high above the surface during the day.

26. A subsidence inversion generally tends to last for a relatively ____________________ period of time compared to a radiation inversion.

    a. Short
    b. Long

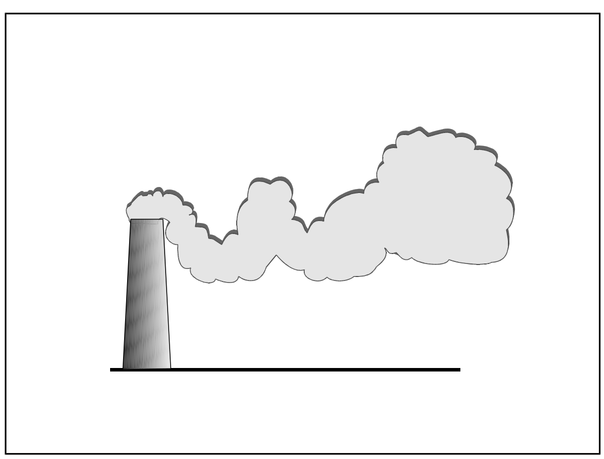
27. Surface-based inversions associated with horizontal air flow, such as when warm air moves over a cold surface, are called ____________________ inversions.

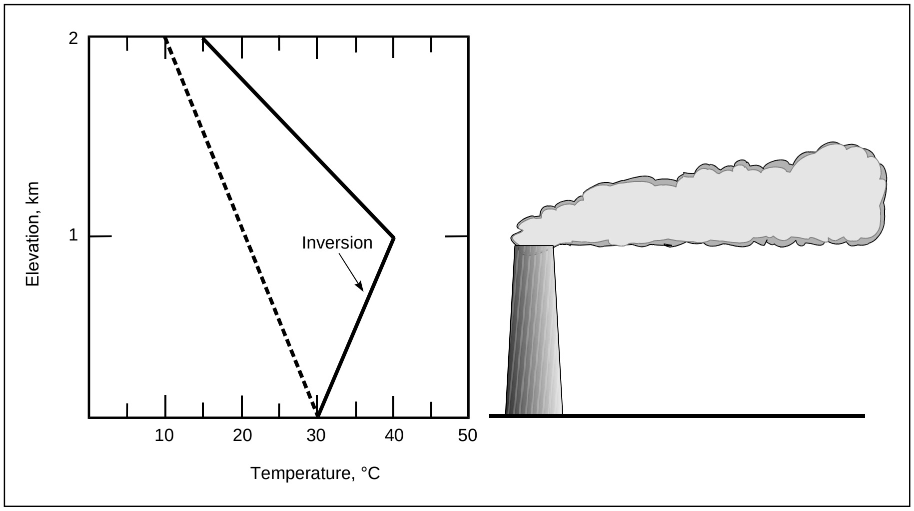
    a. Subsidence
    b. Frontal
    c. Advection
    d. Adiabatic

28. The ____________________ plume is characteristic of neutral or slightly stable atmospheric conditions.

    a. Fanning
    b. Looping
    c. Coning
    d. Lofting

29. What is the name of the plume depicted in this illustration? ____________________





30. Which plume is represented by this lapse rate and stack height?____________________

31. A fanning plume will occur when atmospheric conditions are generally:

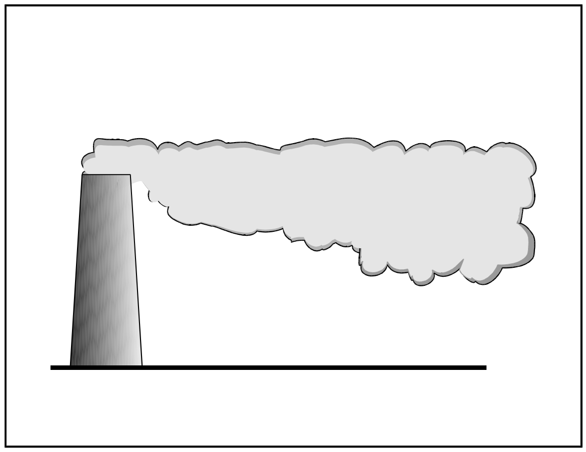
    a. Highly unstable
    b. Stable
    c. Neutral

32. The looping plume can cause ____________________ ground-level concentrations of air pollutants.

33. If a plume is released just ____________________ an inversion layer, a serious air pollution situation could develop.

    a. Under
    b. Over

34. The plume in this drawing is an example of ____________________.



a. Coning
b. Looping
c. Fumigation
d. Lofting

Review Exercise Answers

1. **c. Air parcel**

   An infinitesimally small, well-defined body of air that does not readily mix with the surrounding air is called an air parcel.

2. **a. Increases**

   The temperature of air increases as atmospheric pressure increases.

3. **Temperature and pressure**

   Temperature and pressure are two atmospheric factors that influence the buoyancy of an air parcel.

4. **b. Descend**

   If the temperature of an air parcel is cooler than the surrounding air, it will usually descend.

5. **c. Temperature profile of the atmosphere**

   The environmental, or prevailing, lapse rate can be determined from the temperature profile of the atmosphere.

6. **b. Adiabatic**

   Changes in the temperature of an air parcel that are due to changes in atmospheric pressure are called adiabatic.

7. **c. –9.8°C/1000 m**

   The dry adiabatic lapse rate is –9.8°C/1000 m.

8. **a. True**

   The dry adiabatic lapse rate is fixed and entirely independent of ambient air temperature.

9. **Saturated**

   A displaced air parcel cools at the wet adiabatic lapse rate once it becomes saturated.

10. **b. Slower than at the dry rate**

    At the wet adiabatic lapse rate, the cooling rate of the air parcel is usually slower than at the dry rate.

11. **Environmental**

    The actual temperature profile of the ambient air can be used to determine the environmental lapse rate.

12. **a. True**

The environmental lapse rate influences the extent to which a parcel of air can rise or descend.

13. **c. Mixing height**

The maximum level to which a parcel of air will ascend under a given set of conditions is known as the mixing height.

14. **c. Mixing height**

The adiabatic lapse rate for a given air parcel will intersect the environmental lapse rate at the mixing height.

15. **a. Greater**

A large mixing layer implies that air pollutants have a greater volume of air for dilution.

16. **a. True**

A stable atmosphere resists vertical motion.

17. **a. Unstable**

Vertical mixing due to buoyancy is increased when atmospheric conditions are unstable.

18. **b. On sunny days**

Unstable atmospheric conditions most commonly develop on sunny days.

19. **b. Neutral**

On cloudy days with no strong surface heating, atmospheric conditions are likely to be neutral.

20. **d. Conditional instability above 2 km**

The diagram depicts conditional instability above 2 km.

21. **Inversion**

An inversion acts as a lid on vertical air movement.

22. **Radiation**

When the earth's surface cools rapidly, such as between late night and early morning under clear skies, a radiation inversion is likely to occur.

23. **b. Be dispersed away from their source**

When vigorous vertical mixing follows a radiation inversion, pollutant plumes will be dispersed away from their source.

24. **a. True**

    A high pressure system can cause an elevated temperature inversion to form (subsidence inversion).

25. **Anticyclones**

    The subsidence inversion is associated with anticyclones because it usually forms <u>high above</u> the surface during the day.

26. **b. Long**

    A subsidence inversion generally tends to last for a relatively <u>long</u> period of time compared to a radiation inversion.

27. **c. Advection**

    Surface-based inversions associated with horizontal air flow, such as when warm air moves over a cold surface, are called advection inversions.

28. **c. Coning**

    The coning plume is characteristic of neutral or slightly stable atmospheric conditions.

29. **Looping**

    A looping plume is depicted in this illustration.

30. **Lofting**

    A lofting plume is represented by this lapse rate and stack height.

31. **b. Stable**

    A fanning plume will occur when atmospheric conditions are generally stable.

32. **High**

    The looping plume can cause high ground-level concentrations of air pollutants.

33. **a. Under**

    If a plume is released just <u>under</u> an inversion layer, a serious air pollution situation could develop.

34. **c. Fumigation**

    The plume in this drawing is an example of fumigation.